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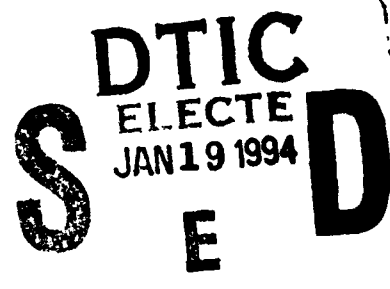
**MONITORING EARTHQUAKE AND EXPLOSION SOURCES
IN THE SOVIET UNION**

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1. INTRODUCTION

This report describes the results of five research projects conducted at Weston Observatory under Contract No. F19628-90-K-0035. The research conducted under this contract covers a range of topics related to seismology in general and to nuclear test monitoring in particular. Details of the results of each project are described in the following five Scientific Reports:

- **Database Relations for Seismic Phases Reported by Stations in the Former Soviet Union**, Scientific Report No. 5, by Alan L. Kafka. This report describes a project in which computer software was developed to produce database relations for seismic phases reported by stations in the former Soviet Union. The programs written for this project read data extracted from the computer files of seismic phase data compiled by the International Seismological Centre (ISC) and create database relations containing ISC phase data for a given station. These relations are stored in computer files in the standardized format that is used by the database management system (DBMS) operating at the Center for Seismic Studies (CSS).
- **Site Effects on Regional Seismograms Recorded in the Vicinity of Weston Observatory**, Scientific Report No. 4, by Matthew R. Jacobson-Carroll and Alan L. Kafka. In this study, we investigated the variation of amplitudes of seismic waves recorded in the vicinity of Weston Observatory. The data used for this study consisted of seismograms recorded from events located at regional distances from the Observatory. The data were recorded on a seismic array that was specifically designed for this study.
- **Tomographic Analysis of the Three-dimensional Seismic Velocity Structure of the Shallow Crust Beneath Southern New England**, Scientific Report No. 3, by Allyn K. Bowers and Alan L. Kafka. In this study, we used tomographic inversion to investigate the three-dimensional variation of the seismic velocity structure of the shallow crust underlying southern New England.
- **Relationship Between Geology and Shallow Crustal Structure in Southern New England**, Scientific Report No. 2, by Susan E. D'Annolfo and Alan L. Kafka. In this study, group velocity dispersion was determined for Rayleigh waves between periods of 0.2 and 2.2 sec recorded from blasts detonated at the San-Vel quarry in Littleton, MA. The resulting dispersion curves were analyzed to investigate the relationship between geologic features and the shallow crustal structure beneath eastern Massachusetts and southern New Hampshire.

- **Geophysical Data Acquisition Systems Users Manual**, Scientific Report No. 1, by Joseph I. Blaney. This report is a users guide for the Geophysical Data Acquisition System (GDAS), which was jointly developed by Weston Observatory and Phillips Laboratory. The GDAS has been used at Weston Observatory for over ten years and has played a significant role in several research projects at the Observatory. The GDAS was used to record data for the study described in Scientific Report No. 4.

In this Final Report, we summarize our results for each of the research projects discussed in these Scientific Reports.

2. DATABASE RELATIONS FOR SEISMIC PHASES REPORTED BY STATIONS IN THE FORMER SOVIET UNION

This project addressed one aspect of monitoring nuclear explosions in a given area using a particular set of seismic stations. To evaluate the extent to which a given set of stations can be used to monitor explosions, it is important to know what seismic phases can be observed at those stations from events of a given size and type occurring in the area being monitored. It is possible to obtain a preliminary assessment of what phases could be recorded at a given station by analyzing phases that have actually been reported to the ISC as part of routine monitoring of earthquakes and explosions. Since there would inevitably be questions regarding the completeness and reliability of phase information provided by station operators in a foreign country, it would be helpful to examine in advance the reporting characteristics of any station that might eventually be used in a treaty verification scenario. This type of information could be useful for estimating how clearly a given seismic phase generated by a nuclear test could be recorded at a given station, if the U.S. were to monitor that particular station for that specific phase.

Most of the work for this project involved writing computer programs to create database relations containing seismic phases reported by stations in the former Soviet Union. These programs, which are described in Scientific Report No. 5, read data extracted from the ISC computer files and create database relations containing ISC phase data for a given station. The phase data for those relations are stored in computer files in the standardized format that is used by the database management system (DBMS) operating at the CSS (Anderson et al., 1990).

There are 168 seismic stations in the former Soviet Union that are described in a report by Shishkevish (1974). Of these stations, at least 148 report (or have previously reported) seismic

phase data in the ISC bulletins. Figure 1 shows the locations of stations in the former Soviet Union that we have been able to identify as reporting phase data to the ISC, and the names and locations of those stations are listed in Scientific Report No. 5.

The ISC data have been recorded on a CD-ROM, and software is available to extract phase data from that CD-ROM (USGS/NEIC, 1990). The USGS/NEIC program that extracts phase data from the CD-ROM is called FAISE (Fetch Associated Information of Seismic Events). Using the FAISE software and the CD-ROM as a starting point, we extracted phase data reported for specific stations in the former Soviet Union. We have written computer programs that read the output from FAISE, and translate that output into the standardized "external format" that is used by the DBMS operating at the CSS.

The structure of the database used at the Center for Seismic Studies (CSS) is described by Anderson et al. (1990). The specific database relations that have been created for this project are **arrival**, **assoc**, **event** and **origin**. The programs that create these relations from the FAISE output are written in C, and the C code for each program is listed in the Appendices of Scientific Report No. 5.

While the results presented in this report were obtained by running the programs on a Macintosh computer, the C code should be completely portable to other computers. We have successfully run these programs on a DEC-VAX computer operating under the VMS operating system, as well as on several IBM-PC compatible computers operating under the DOS operating system. In all cases, the only changes that were necessary were very minor changes to the C header statements. Since the FAISE program runs in the DOS operating system, the use of these programs on a DOS computer would make it possible to efficiently extract the necessary relations for any station and any time period covered by the ISC CD-ROM catalogue.

Using the months of January 1984 and January 1986 and the stations OBN and YAK as examples, we illustrate the type of information that is contained in a database created by the programs written for this project. Figure 2 shows all events in the ISC Bulletin (with $m_b > 0$) reported during January 1984 and January 1986. Figure 3 shows the event epicenters corresponding to a "station-phase" catalogue for OBN - January 1986, i.e. all events for which at least one phase was reported by station OBN during January 1986. For comparison with Figure 3, Figure 4 shows epicenters corresponding to the station-phase catalogue for YAK - January 1986. Station OBN only reported phases for events within the former Soviet Union and immediate surrounding areas. YAK, on the other hand, reported phases not only from events within and in

the vicinity of the former Soviet Union, but also from events in the western United States, western South America and the southern Atlantic ocean. This difference is at least in part due to the fact that YAK is closer to those particular areas in the Western Hemisphere than OBN, but could also be due to differences in station characteristics (e.g. lower background noise).

For comparison with these Soviet station-phase catalogues, Figures 5 and 6 show epicenters corresponding to the station-phase catalogues for two United States stations, BLA - January 1986 and GOL - January 1986, respectively. A more detailed description of the differences in number and type of reported phases at a sample of Soviet and United States stations is given in Scientific Report No. 5.

Once the programs for all of the relations have been run for a given station and time period, the data can be read into the DBMS. For the examples described below, we used the ORACLE DBMS operating on a Macintosh computer. The commands for reading the data and creating the necessary tables are written in the Structured Query Language (SQL). Tables 1 and 2 show the results of using SQL queries to extract information about specific phases reported by OBN and YAK for January 1986. The SQL command that generated the results shown in Tables 1 and 2 was:

```
SELECT ARRIVAL.STA, EVNAME, DELTA, MB, QUAL, IPHASE
FROM   ORIGIN, ARRIVAL, ASSOC, EVENT
WHERE  ARRIVAL.ARID = ASSOC.ARID
AND    ASSOC.ORID = ORIGIN.ORID
AND    ORIGIN.EVID = EVENT.EVID;
```

We illustrate several examples of using SQL queries to extract information for specific time periods for selected Soviet stations (OBN, YAK and NVS) and for selected U.S. stations (BLA, GOL and ALQ). Although the programs written for this project can be run for any time period covered by the ISC data base (i.e. January 1964 through August 1987), we use one-month time segments in these examples because the number of phases reported in a longer period of time can result in quite large output files.

Tables 3 and 4 show the results of executing the same SQL command that generated the results shown in Tables 1 and 2, but in this case for United States stations BLA and GOL, respectively. The computer programs and SQL statements described in this report were tested empirically by comparing the results of running a database search with information listed in the corresponding "hard copy" ISC Bulletin. These tests revealed no obvious errors in any of the programs or SQL statements.

To illustrate the type of analysis that can be done once the data base has been created and loaded into ORACLE, we executed the following SQL query for the month of January 1986 at stations OBN, YAK, NVS, BLA, GOL and ALQ.

```
SELECT IPHASE, COUNT(*)
FROM  ORIGIN, ARRIVAL, ASSOC, EVENT
WHERE ARRIVAL.ARID = ASSOC.ARID
AND ASSOC.ORID = ORIGIN.ORID
AND ORIGIN.EVID = EVENT.EVID;
AND ARRIVAL.STA = ASSOC.STA
GROUP BY IPHASE;
```

The results of executing this command are shown in Table 5, which lists the number of times a given phase was reported during January 1986 at stations OBN, YAK, NVS, BLA, GOL and ALQ. Table 6 shows the same information for the month of January 1984.

Although it is beyond the scope of this report to present a detailed analysis of all the information that could be extracted for the Soviet and United States stations using the data base created by these programs, it is helpful to continue our simple example as a way of further illustrating the type of analysis that can be done. Note in Tables 1 and 2 for example, that in both January 1986 and January 1984, all three of the Soviet stations were reporting S phases, while only one S phase (at ALQ in 1984) was reported for all three United States stations. Also, based on these two months, it appears that the phase pP is routinely reported by OBN and YAK in the former Soviet Union, and by GOL and ALQ in the United States. However, for some reason pP is not reported by NVS and BLA. It is also interesting to note in Tables 5 and 6 that the ratio of reported P phases to reported PKP phases is fairly consistent for a given station.

While the pattern of reporting from the Soviet stations is quite uniform for both months and all three stations, the pattern is not uniform from one United States station to the next. Station ALQ reports many more phases than GOL, and BLA reports less phases than any of the other United States or Soviet stations. The DBMS can be used to investigate what might be the cause(s) of such differences. For example, Table 7 shows the results of executing the following SQL command for the GOL - January 1984 station-phase data base:

```
SELECT ARRIVAL.STA, IPHASE, EVNAME, DELTA, MB, LAT, LON
FROM  ORIGIN, ARRIVAL, ASSOC, EVENT
WHERE ARRIVAL.ARID = ASSOC.ARID
AND ASSOC.ORID = ORIGIN.ORID
AND ORIGIN.EVID = EVENT.EVID;
AND ARRIVAL.STA = ASSOC.STA
AND IPHASE = 'P'
ORDER BY DELTA;
```

Executing that same SQL command for the ALQ - January 1984 station-phase data base, and comparing the output with that shown for GOL in Table 7, we found that about half of the difference between the outputs for GOL and ALQ can be explained by the fact that ALQ reported many more foreshocks and aftershocks of a given event than GOL did. Additional illustrations of the use of the database created by the programs written for this project are given in Scientific Report No. 5.

While the original intent of this project was to develop a data base of seismic phases reported by stations in the former Soviet Union, the programs written for this project can be used for any station that reports to the ISC. This makes it possible to obtain a preliminary assessment of what phases could be recorded at a given station in any part of the world by analyzing phases that have actually been reported as part of routine seismic monitoring.

3. SITE EFFECTS ON REGIONAL SEISMOGRAMS RECORDED IN THE VICINITY OF WESTON OBSERVATORY

A key issue in monitoring nuclear explosions is the extent to which details of the earth structure in the vicinity of a recording site can affect amplitudes and waveforms of seismic waves. In an effort to address this issue, we installed a seismic array (the Weston Seismic Array, WESSA) in the area surrounding Weston Observatory. The purpose of this experiment was to investigate the variation of amplitudes and waveforms of seismic waves recorded at distances up to about 0.5 km from the permanent seismic stations operating at Weston Observatory.

The WESSA originally consisted of eight sites with 1-Hz vertical seismometers extending out to about 0.25 km from the reference site, but has been recently extended to include twelve sites extending out to about 0.5 km (Figure 7). The extended array includes NS and EW components at the reference site in addition to the vertical seismometers at that site. The configuration of the array is described in greater detail below in Section 6 of this report and also in Scientific Report No. 4. So far, we have only completed the analysis of data recorded by the original 0.25 km aperture array, and results discussed in this report are primarily based on that smaller array.

The array includes a combination of instruments on bedrock, bedrock-coupled piers and other instruments mounted in a soil cover of up to 10 meters above bedrock. It also includes a cluster of nearly co-located instruments. Many of the inter-sensor distances are well within the range over which background noise remains correlated.

Jacobson-Carroll and Kafka (1992) used signals recorded by the WESSA from quarry blasts in New England to investigate the extent to which site effects in the vicinity of Weston Observatory cause variations in amplitudes and waveforms of seismic waves. They calculated spectral amplitude ratios between channels for cases in which the type of siting (pier-mount/bedrock vs. soil sites) and inter-sensor distances vary. Complete seismograms of about 20 sec duration, including initial noise segments followed by P, S/Lg, and Rg arrivals, were analyzed to compute those spectral ratios. They found that, due to what appeared to be site effects, spectral amplitudes varied by nearly a factor of two at bedrock sites and by as much as a factor of five at soil-covered sites (where the soil layer thickness was about 5 to 6 m). Figure 8 shows an example in which amplitude variations up to a factor of 2.5 are evident. Some of those apparent amplitude variations are clearly due to background noise at site G, rather than actual differences in signal amplitudes. We are in the process of conducting a detailed study in which we are attempting to separate true site effects from effects of background noise interfering with the signals. Based on the lack of an obvious trend toward greater variation in amplitudes for sites separated by greater distances, our preliminary results suggest that for this type of experiment site effects play a larger role than propagation effects, at least on the scale of a few tenths of a kilometer.

4. RELATIONSHIP BETWEEN GEOLOGY AND SHALLOW CRUSTAL STRUCTURE IN SOUTHERN NEW ENGLAND

Studies of shallow crustal structure using Rg wave dispersion have shown that the dispersion patterns in southern New England (SNE) exhibit differences in group velocity from one area to the next (e.g. Kafka and Dollin, 1985; Kafka, 1988). Rg is a short period fundamental mode Rayleigh wave, and the dispersive properties of Rg waves are sensitive to variations in the seismic velocity structure of the shallow crust. Quarry blasts and very shallow-focus earthquakes produce strong Rg waves that are clearly recorded at stations of the New England Seismic Network (NESN). Seismograms generated by these two kinds of sources were used in the Rg dispersion studies described in this report.

Kafka and Skehan (1990) divided SNE into five regions which appeared to have distinct Rg dispersion characteristics, and they referred to those regions as Rg "dispersion regions." The most clearly distinct dispersion region in their study of SNE is the central portion of the Hartford Rift basin (Figure 9), where Rg group velocities are distinctly lower than they are in other parts of SNE (Figure 10). The lower group velocities found for paths crossing the Hartford Rift basin are presumably due to the abundance of sediments and sedimentary rocks in that area.

Previous to our study described in Scientific Report No. 2, the rather large area that extends from the Bronson Hill Anticlinorium to the Avalonian Terrane (Figure 9) was found to be characterized by very little variation in Rg group velocities (Figure 10). This observation suggested that the shallow crust underlying that area is laterally homogeneous (at least at the scale of features revealed by previous Rg dispersion studies). Because of that lack of observed lateral variation, Kafka and Skehan (1990) characterized that entire area as one Rg dispersion region, which they called the Bronson Avalon Dispersion Region (BADR).

One area that was thought to be characterized by distinctly higher Rg group velocities than the BADR was in the southwestern part of Connecticut (e.g. Kafka and Dollin, 1985). In a more recent study, however, Kafka and Bowers (1991) showed that southwestern Connecticut is actually characterized by Rg group velocities quite similar to those of the BADR. Additional analysis of Rg dispersion in southern New Hampshire and adjacent Vermont (Tu, 1990) suggested that the area of laterally homogeneous shallow crust extends to the northeast of the BADR (Figure 9). Thus, it appears that all areas in SNE where crystalline basement is at or near the surface have (at least on average) group velocities similar to those of the BADR, and it is probably more appropriate to refer to the parts of SNE on both sides of the Hartford Rift basin as one Rg dispersion region, which we call the Southern New England Crystalline Basement (SNECB). Since this entire area includes a wide range of geological structures and rock types, it is surprising that it appears to be so homogeneous. The Rg dispersion pattern seems to ignore the transition from one geological feature to the next. It is interesting to note in this regard that, based on refraction/wide-angle reflection experiments in northern New England, Hughes and Luetgert (1991) found the seismic velocity structure of the New England Appalachian crust to be significantly lacking in lateral velocity variations.

In contrast to SNE, there is at least one other area of New England (southeastern Maine) where significant differences in Rg dispersion have been observed that appear to correlate with the geology of the crystalline basement structures. Kafka and Reiter (1987) found evidence for lateral anisotropy in the shallow crust of southeastern Maine, where the trend of the anisotropy is parallel to the structural grain of the Appalachians. Thus the question arises: Does the seismic velocity structure of the shallow crust beneath the SNECB really have no systematic relationship to the surface mapped geology? Alternatively, does the relationship between the surface geology and shallow crustal structure exist at a scale that is too small to be seen by the distribution of paths in previous Rg dispersion studies?

To address these questions, D'Annolfo and Kafka (1992) investigated lateral variations in the seismic velocity structure of the shallow crust beneath eastern MA and southern NH in greater detail than had been done in the past. For this research, we used field data to obtain a denser station spacing than was available using just the NESN stations. Using both field data and NESN data, we analyzed group velocity dispersion of Rg waves recorded from quarry blasts detonated at the San-Vel quarry in Littleton, MA to investigate the extent of lateral variation in the shallow crust surrounding that quarry. The purpose of this investigation was to determine whether or not the lack of observed variation of Rg dispersion within the SNECB was an artifact of the relatively sparse distribution of paths.

The results of this study (described in detail in Scientific Report No. 2) suggest that there is indeed systematic lateral variation in the structure of the shallow crust underlying eastern MA and southern NH. However, this lateral variation is not very pronounced, and it seems to require these detailed types of experiments for the lateral variation to be observed. Within the area investigated in this study, lateral variation in group velocity appears to depend on distance from the San-Vel quarry. Three dimensional plots of the group velocity data (Figure 11) reveal that the San-Vel quarry appears to lie in a "trough" of particularly low group velocities, where the group velocities systematically increase toward the east and west-northwest directions. This creates a "U-shaped valley" of group velocities where the primary trend of the valley trough trends in a north-south direction, and a secondary feature is a "valley" that trends in a northeast direction. This northeast trending feature is of particular interest because of a possible correlation with the structural geology of the area, particularly the trend of the Clinton-Newbury fault zone which forms the boundary between the Merrimack trough and the Putnam-Nashoba terrane. One possible explanation of this result is that the group velocities are lower in the vicinity of the fault because the rocks in that area are more fractured and faulted than in the surrounding areas.

5. TOMOGRAPHIC ANALYSIS OF THREE-DIMENSIONAL SEISMIC VELOCITY STRUCTURE OF THE SHALLOW CRUST BENEATH SOUTHERN NEW ENGLAND

The seismic velocity structure beneath SNE has been extensively studied using both body wave and surface wave data (e.g. Chiburis et al., 1977; Taylor and Toksoz, 1979, 1982; Wenk, 1984, 1987). More recently, a number of studies have used the dispersive properties of Rg waves to study the velocity structure of the upper few kilometers of the crust beneath SNE (e.g. Kafka and Dollin, 1985; McTigue, 1986; Saikia et al., 1990; Gnewuch, 1987; Kafka and Skehan, 1990; Tu, 1990; Kafka and Bowers, 1991; Kafka and D'Annolfo, 1992). In all of these previous Rg dispersion studies, group velocity was measured for each source-receiver path at a range of periods to determine lateral variation in group velocity dispersion. In several of these studies, the dispersion curves for specific paths and/or the average dispersion curve for a specific area were inverted to yield an estimate of the shear wave velocity structure of the shallow crust beneath some part of SNE. These results were then used to assess the extent of lateral and vertical variation in the seismic structure of the shallow crust.

The resulting models of the seismic velocity structure of the shallow crust beneath SNE have suggested that there is both lateral and vertical variation in the seismic velocity structure of the upper few kilometers of the SNE crust. However, a more complete picture of what can and cannot be said about the three-dimensional variation of the velocity structure based on the observed Rg data from all of these previous Rg dispersion studies can be obtained by systematically analyzing the data using computer tomography. Furthermore, a tomographic study that isolates dispersion for segments of paths rather than depending on dispersion for the entire length of each path may effectively isolate dispersion data for subregions within SNE that have not been identified in previous studies. This research project (described in detail in Scientific Report No. 3) was such a systematic tomographic study.

One of the problems encountered in addressing this topic is that the group velocity data from all of the Rg studies in SNE exhibit a very large amount of scatter. Nonetheless, there does appear to be a systematic "signal" buried within this "noise". The following fundamental questions provide the underlying framework for this study:

- 1) In spite of the very large amount of scatter in the group velocity data, to what extent can a tomographic analysis of that data delineate lateral variation in Rg dispersion across SNE?

2) Once the dispersive characteristics have been estimated for a given sub-region of the study area, how accurately can one estimate the vertical variation of the shear wave velocity structure beneath that sub-region?

To address the first question, we systematically analyzed the lateral variation of Rg group velocities obtained from the studies published since 1985 and from our own analyses of seismograms recorded in SNE. This systematic analysis involved the use of computer tomography to estimate the lateral variation in group velocity across SNE. First, the study area was divided into equally-sized blocks. Paths whose source and receiver are contained within the study area are superimposed over the block structure and divided into segments by the boundaries of each block. Rg group velocities were converted to group travel times for selected frequencies, and tomography was then used to estimate the group velocity within each block. Finally, group velocities were compared between adjacent blocks. A judgement was made as to whether the resulting differences in group velocity were due to 1) actual velocity variation within the earth's crust, 2) errors introduced into the analysis because of the way the problem was formulated, or 3) errors mapped from the observed data into the tomographic solution.

To address the second question, the maximum likelihood inverse method was used to estimate the vertical variation in shear wave velocity (e.g. Menke, 1984; Reiter et al., 1988). For a given sub-region of the study area, the observed group velocity at a specific frequency is indicative of shear wave velocities at some range of depths. Once the tomographic analysis was successfully carried out, group velocities were estimated at a range of frequencies for specific blocks, which yielded a dispersion curve for each of those blocks. A shear wave velocity model was then estimated for each block by a combination of inversion and forward modeling of the dispersion curve corresponding to that block.

Examples of our results for this project are shown in Figures 12 and 13. Scientific Report No. 3 gives a more detailed description of our results for the tomographic inversion and the specifics of how those results were obtained.

A general summary of our current models of the upper crust beneath the SNECB is given in Table 8 and Figure 14. A composite model of the shallow and deeper crust was created by combining the results of our inverted Rg model for the average structure underlying the SNECB with the refraction/wide-angle reflection model of the Appalachians described by Hughes and Luetgert (1991). The models were "connected" together at depth of about 3 km. In creating this composite model we "forced" the velocity structure to increase monotonically with depth (i.e. the

low velocity layer between 1.6 and 2.4 km depth in the Rg model was not included). Instead, we combined that layer with the one directly above it, and used the average velocity for those two layers for the velocity within the combined layer. For the Hughes and Luetgert model, we used their estimates of Poisson's ratio to obtain V_S from V_P , i.e. 0.24 in the upper crust and 0.265 in the lower crust. (The value of 0.265 for Poisson's ratio in the lower crust is the midrange of the 0.26-0.27 range given by Hughes and Luetgert.) We also used 0.265 for the value of Poisson's ratio in the mantle. For the Rg models, we obtained V_P from V_S by using a value of 0.25 for Poisson's ratio.

6. THE GEOPHYSICAL DATA ACQUISITION SYSTEM

The Geophysical Data Acquisition System (GDAS) is a semi-portable, computer controlled data acquisition system designed to operate under DEC's RT11 Version 5.2 operating system. The GDAS and its software were jointly developed by Weston Observatory and the Phillips Laboratory. The GDAS has been used at Weston Observatory for over ten years and has played a significant role in several research projects at the Observatory. The GDAS was used to record data for our study of the extent to which site effects in the vicinity of the Observatory cause variations in amplitudes and waveforms of seismic waves (described in Scientific Report No. 4).

Using the GDAS as a recording system, we installed, and recently expanded, a seismic array (the Weston Seismic Array, WESSA) in the area surrounding Weston Observatory. The original WESSA (Figure 7a) consisted of thirteen 1-Hz vertical seismometers installed at distances up to about 0.25 km from the main recording piers of station WES, including seismometers on four bedrock-anchored seismic recording piers (sites A, B, C and D in Figure 7a). That array has recently been expanded to include five additional sites with some at distances up to about 0.5 km from the reference station at site A (Figure 7b). Site D was discontinued in the new array configuration. All of the sites have vertical 1-Hz seismometers, and the expanded array also includes NS and EW horizontal instruments at the reference site (site A). The original array did not have an event trigger, and events recorded on the original array are quarry and construction blasts (for which we had advance warning of the event time). An event trigger algorithm has recently been installed, and data are now being recorded by the system in trigger mode.

Part of our work for this contract involved comparing signals recorded by seismometers directly adjacent to each other to estimate the fundamental level of precision with which we are capable of measuring amplitudes and waveforms. Seismometers are therefore located directly

adjacent to each other at the reference site, and at site B (43 m from the reference site and about 5 m from the WWSSN piers). Five seismometers are buried in soil overlying bedrock (i.e. at sites E, F, G, H and I). The thickness of the soil cover at these sites is on the order of 3 to 10 m.

The data from the WESSA are recorded by the GDAS at 50 samples per sec, and all of the seismometers are connected to the GDAS by cables. The system is calibrated with the seismometers deployed at their field sites by applying a known current to the calibration coils of the seismometers. Estimates of the system response are obtained through a least-squares fit of a theoretical model to the observed calibration pulses.

Nearly all of the events recorded by the original array were quarry blasts, although we also recorded a relatively large construction blast detonated in Boston Harbor (located about 30 km from the array). Now that the trigger algorithm is functioning, we are also recording earthquakes on the array, including numerous teleseisms which provide strong signals at frequencies near 1-Hz. Figure 8 shows examples of seismograms recorded by the array from a quarry blast about 25 km from the Observatory. We can directly compare amplitudes and waveforms between seismograms in that figure because the seismograms have been processed to appear as if they were recorded by the same instrument. This was accomplished by first deconvolving the system response and then convolving the resulting ground motion through a theoretical instrument with a response similar to that of channel 3 (located at the reference site).

Table 1

STA	EVNAME	DELTA	MB	Q	IPHASE
OBN	198601 1 6 9 63	16.42	4.8	e	P
OBN	198601 12210261	61.55	5.1	e	P
OBN	198601 3 943273	90.97	5.4	e	P
OBN	198601 3 943273	90.97	5.4	i	S
OBN	198601 31558 94	62.94	5	e	P
OBN	198601 31558 94	62.94	5	e	S
OBN	198601 4 952537	127.31	5		PKP
OBN	198601 41336337	127.31	5.3		PKP
OBN	198601 5 2 7362	127.34	4.7	e	PKP
OBN	198601 5 921310	65.47	5		P
OBN	198601 5 921310	65.47	5	e	pp
OBN	198601 6 0 9 95	16.74	4.8	e	P
OBN	198601 6 0 9 95	16.74	4.8	i	S
OBN	198601 61737201	35.77	4.9		P
OBN	198601 71312 84	89.2	5	e	P
OBN	198601 71355 16	71.25	4.9	e	P
OBN	198601 71355 16	71.25	4.9	e	pp
OBN	198601 8 027207	18.68	4.2	e	P
OBN	198601 8 027207	18.68	4.2	e	S
OBN	19860110 346309	44.35	5.5		P
OBN	19860110 346309	44.35	5.5	e	pp
OBN	19860110 346309	44.35	5.5	e	S
OBN	19860110 6 2585	75.19	4.9	e	P
OBN	19860111115 1 75	18.63	4.3	e	P
OBN	198601122014557	31	5.4		P
OBN	198601122014557	31	5.4	e	S
OBN	198601131157193	69.52	5.2	e	P
OBN	198601131348 36	17.88	4.8		P
OBN	19860114 3 3373	30.05	5.2		P
OBN	19860114 3 3373	30.05	5.2	e	S
OBN	19860116 5 8347	84.86	5.5		P
OBN	19860116 5 8347	84.86	5.5	e	pp
OBN	19860116 5 8347	84.86	5.5	e	S
OBN	19860116 834447	72.52	5.1		P
OBN	198601161111599	74.94	5.1	e	P
OBN	1986011613 4312	67.5	5.4		P
OBN	1986011613 4312	67.5	5.4	e	sp
OBN	1986011613 4312	67.5	5.4	e	S
OBN	19860117 753454	85.15	4.8		P
OBN	19860118 744487	55.29	5.2		P
OBN	19860118 744487	55.29	5.2	e	sp
OBN	19860118 756240	125.39	5.1		PKP
OBN	19860119 635510	76.99	5.2		P
OBN	198601191445465	34.11	5	e	P
OBN	19860122 2 1156	32.74	4.4		P
OBN	19860122 758399	29.24	4.2	e	P
OBN	198601221226458	117.56	5.9	e	PKP
OBN	198601221457132	89.07	5.6		P
OBN	198601221457132	89.07	5.6	e	pp
OBN	19860123 816 46	63.19	4.9	e	P
OBN	1986012516 0415	28.86	5.1	e	P
OBN	19860127 243575	69.55	4.9	e	P
OBN	19860127 719343	21.91	4.6	e	P
OBN	198601271635514	18.16	5.3		P

Table 1 (Continued)

OBN	198601271635514	18.16	5.3 e S
OBN	198601281232168	64.62	5.7 P
OBN	198601281232168	64.62	5.7 e S
OBN	19860129 927419	89.55	5.3 P
OBN	198601311748 42	64.63	5.1 P
OBN	198601311748 42	64.63	5.1 e sP

60 records selected.

Table 2

STA	EVNAME	DELTA	MB	Q	IPHASE
YAK	198601161545 67	48.68	5.3	i	pP
YAK	198601161545 67	48.68	5.3	i	S
YAK	198601161853 50	34.72	4.8		P
YAK	19860117 753454	58.76	4.8		P
YAK	19860118 158589	31.97	5.8		P
YAK	19860118 158589	31.97	5.8	i	S
YAK	19860118 158589	31.97	5.8	i	sS
YAK	19860118 744487	47.15	5.2		P
YAK	19860118 756240	82.76	5.1		P
YAK	19860119 635510	36.18	5.2		P
YAK	19860119 635510	36.18	5.2	i	S
YAK	198601191445465	49.08	5		P
YAK	198601192225571	31.57	4.8	e	P
YAK	198601201928226	37.45	4.5		P
YAK	1986012022 1161	37.49	4.7		P
YAK	19860122 2 1156	51.41	4.4	e	P
YAK	198601221226458	75.97	5.9		P
YAK	198601221226458	75.97	5.9	i	sP
YAK	19860114 3 3373	44.07	5.2	i	pP
YAK	19860114 3 3373	44.07	5.2	i	sP
YAK	19860114 3 3373	44.07	5.2	i	S
YAK	198601141157492	37.47	5.1		P
YAK	198601141856299	37.47	5.1		P
YAK	1986011419 5 54	37.45	5.1		P
YAK	198601151730273	37.47	4.8		P
YAK	198601152017312	89.17	6		P
YAK	198601152017312	89.17	6	e	S
YAK	19860116 5 8347	56	5.5		P
YAK	19860116 5 8347	56	5.5	i	SP
YAK	19860116 834447	32.75	5.1	e	P
YAK	19860116 834447	32.75	5.1	i	S
YAK	198601161111599	34.67	5.1		P
YAK	1986011613 4312	37.6	5.4		P
YAK	1986011613 4312	37.6	5.4	e	S
YAK	1986011613 4312	37.6	5.4	i	ScP
YAK	198601161545 67	48.68	5.3		P
YAK	198601 92141551	21.41	4.5		P
YAK	198601 92141551	21.41	4.5	i	sP
YAK	198601 92141551	21.41	4.5	i	S
YAK	19860110 346309	43.69	5.5		P
YAK	19860110 346309	43.69	5.5	i	S
YAK	19860110 6 2585	34.95	4.9		P
YAK	198601111231146	80.93	5.2		P
YAK	198601111350137	69	5.1		P
YAK	198601111350137	69	5.1	i	S
YAK	198601122014557	46.52	5.4		P
YAK	198601122014557	46.52	5.4	i	S
YAK	198601122343182	19.61	5		P
YAK	198601122343182	19.61	5	i	S
YAK	19860113 842250	37.48	4.8		P
YAK	198601131157193	38.72	5.2	e	P
YAK	198601131742414	69.28	5		P
YAK	198601132322399	63.48	5		P

Table 2 (Continued)

YAK	19860114 3 3373	44.07	5.2	P
YAK	198601 12210261	18.91	5.1	P
YAK	198601 3 224398	145.61	5.2	PKP
YAK	198601 3 943273	62.87	5.4	P
YAK	198601 3 943273	62.87	5.4 i	S
YAK	198601 31558 94	57.47	5	P
YAK	198601 31558 94	57.47	5 i	pP
YAK	198601 31558 94	57.47	5 i	S
YAK	198601 4 952537	84.86	5	P
YAK	198601 41336337	84.84	5.3	P
YAK	198601 5 2 7362	84.95	4.7	P
YAK	198601 5 553521	67.44	5.8	P
YAK	198601 5 921310	21.41	5	P
YAK	198601 5 921310	21.41	5 i	S
YAK	198601 7 8 8466	84.66	5	P
YAK	198601 71038546	92.56	5.2	P
YAK	198601 71038546	92.56	5.2 i	pP
YAK	198601 71355 16	65.57	4.9	P
YAK	198601 9 624425	17.59	4.9 e	P
YAK	198601221226458	75.97	5.9 i	S
YAK	198601221457132	62.43	5.6	P
YAK	198601221457132	62.43	5.6 i	S
YAK	198601221732540	50.4	5.1	P
YAK	19860123 816 46	19.03	4.9	P
YAK	19860123 816 46	19.03	4.9 i	S
YAK	198601231353562	19.25	4.8	P
YAK	198601231353562	19.25	4.8 e	S
YAK	1986012516 0415	35.65	5.1	P
YAK	1986012516 0415	35.65	5.1 i	sS
YAK	19860126 748218	142.41	5.7	PKP
YAK	198601261628554	34.51	4.7 e	P
YAK	198601261628554	34.51	4.7 e	pP
YAK	198601261729528	91.99	5 e	P
YAK	198601261920511	66.26	5.2	P
YAK	19860127 243575	38.73	4.9	P
YAK	19860127 349431	27.42	4.8	P
YAK	19860127 349431	27.42	4.8 i	S
YAK	19860127 349431	27.42	4.8 i	sS
YAK	19860127 735238	76.22	5.5	P
YAK	19860127 735238	76.22	5.5 i	S
YAK	198601271635514	52.47	5.3 e	P
YAK	198601271635514	52.47	5.3 i	S
YAK	198601272032 26	38.21	4.7	P
YAK	19860128 928232	39.29	4.7 e	P
YAK	198601281232168	59.14	5.7	P
YAK	198601281232168	59.14	5.7 i	S
YAK	1986012818 5236	34.26	4.8 e	P
YAK	1986012818 5236	34.26	4.8 e	sS
YAK	1986012820 1287	79.59	4.9	P
YAK	19860129 927419	49.46	5.3	P
YAK	19860129 927419	49.46	5.3 i	S
YAK	19860130 715330	58.01	5.1	P
YAK	19860131 227 32	20.8	4.9 e	P
YAK	198601311437234	153.7	5.1	PKP
YAK	198601311748 42	21.33	5.1	P

Table 2 (Continued)

YAK	198601311748 42	21.33	5.1 e sP
YAK	198601311748 42	21.33	5.1 i S

110 records selected.

Table 3

STA	EVNAME	DELTA	MB	Q	IPHASE
BLA	198601 8 342511	73.03	5.2	e	P
BLA	19860112 638220	41	5.5		P
BLA	19860114 3 9357	32.55	5.2	e	P
BLA	198601141034 21	121.42	5.6		PKP
BLA	19860126 748218	64.52	5.7		P
BLA	198601261920511	32.49	5.2	e	P
BLA	198601291334100	30.4	5.5		P
BLA	198601302226347	30.34	4.9		P
BLA	198601302323289	30.32	4.8		P
BLA	198601311646410	4.41	4.8	e	Pn

10 records selected.

Table 4

STA	EVNAME	DELTA	MB	Q	IPHASE
GOL	19860130 6 6408	25.4	4.5	e	P
GOL	19860130 715330	16.94	5.1	e	P
GOL	198601301641 10	91.91	4.7	e	P
GOL	198601302226347	41.61	4.9	e	P
GOL	198601302323289	41.6	4.8	e	P
GOL	19860131 551406	69.24	4.9	e	P
GOL	19860131 551406	69.24	4.9	e	pP
GOL	198601311646410	18.48	4.8	e	P
GOL	198601311748 42	77.61	5.1	e	P
GOL	198601261920511	12.87	5.2	e	P
GOL	19860127 052374	27.19	4.4	e	P
GOL	19860127 159421	85.17	4.7	e	P
GOL	19860127 349431	53.99	4.8	e	P
GOL	19860127 735238	99.22	5.5	e	P
GOL	198601271021599	91.97	5.2	e	P
GOL	198601271936177	21.67	4.6	e	P
GOL	19860128 651466	48.61	5.2	e	P
GOL	198601281232168	128.49	5.7	e	PKP
GOL	198601281543573	21.77	4.7	i	P
GOL	198601282319 51	85.82	5	e	P
GOL	198601282319 51	85.82	5	e	
GOL	19860129 927419	94.74	5.3		P
GOL	198601291019 52	40.79	4.7	e	P
GOL	198601291334100	41.6	5.5	e	P
GOL	198601291349429	41.58	4.7		P
GOL	198601291447175	41.52	4.7	e	P
GOL	1986012920 1279	22.36	4.6		P
GOL	19860117 415 00	56.02	5.5	e	P
GOL	19860118 158589	47.2	5.8	e	P
GOL	19860119 635510	88.21	5.2	e	P
GOL	19860119 8 3287	45.3	4.9	e	P
GOL	198601191128 14	26.82	4.2	e	P
GOL	19860121 524231	88.53	5.6	e	P
GOL	198601211739490	84.31	4.6	e	P
GOL	198601211739490	84.31	4.6	e	
GOL	1986012212 9562	25.24	4.1	e	P
GOL	198601221226458	99.18	5.9	e	P
GOL	198601221457132	120.24	5.6	i	PKP
GOL	19860125 449417	88.58	5	e	P
GOL	19860125 939465	50.62	5.2	e	P
GOL	198601252023183	148.37	4.8	e	PKP
GOL	198601252023183	148.37	4.8	e	sPKP2
GOL	19860126 748218	73.76	5.7	i	P
GOL	19860126 748218	73.76	5.7	e	sP
GOL	198601 1 437249	25.13	4.6	e	P
GOL	198601 122 1182	20.43	5.2	e	P
GOL	198601 21435598	21.14	4.8	e	P
GOL	198601 22042403	144.41	4.8	e	PKP
GOL	198601 22133425	149.78	4.8	e	PKP
GOL	198601 3 943273	118.86	5.4	e	PKP
GOL	198601 42331 77	20.42	5.1		P
GOL	198601 71038546	91.22	5.2	e	P
GOL	198601 71225139	25.09	4.3	e	P
GOL	198601 8 342511	81.37	5.2	e	P

Table 4 (Continued)

GOL	19860112 638220	49.62	5.5 e P
GOL	198601121651325	21.34	4.7 e P
GOL	198601131232 46	5.2	0 e Pn
GOL	19860116 834447	88.76	5.1 e P
GOL	1986011614 0 77	43.66	4.8 P
GOL	1986011623 7355	88.99	5 P

61 records selected.

Table 5

Phases Reported by Selected Stations in January 1986

Phase	OBN	YAK	NVS	BLA	GOL	ALO
P	36	63	29	8	49	129
PKP	5	3	2	1	6	22
P/PKP ratio	0.14	0.05	0.07	0.13	0.12	0.17
PcP	0	0	0	0	0	2
PcS	0	0	1	0	0	0
Pdiff	0	0	1	0	0	0
Pn	0	0	0	1	1	3
pP	5	5	0	0	1	8
pPKP	0	0	0	0	0	0
S	11	25	16	0	0	0
ScP	0	1	0	0	0	0
ScS	0	0	0	0	0	0
SKS	0	0	0	0	0	0
SP	0	1	1	0	0	0
sP	3	4	0	0	1	0
sPKP2	0	0	0	0	1	0
sS	0	3	0	0	0	0
Unidentified	0	0	0	0	2	0

Table 6

Phases Reported by Selected Stations in January 1984

Phase	OBN	YAK	NVS	BLA	GOL	ALO
P	63	93	62	12	35	126
PKP	7	7	4	2	4	50
P/PKP ratio	0.11	0.08	0.06	0.17	0.11	0.40
PcP	0	0	0	0	0	1
Pdiff	0	0	0	0	1	1
PcS	0	0	0	0	0	0
Pn	0	0	0	0	0	0
pP	7	9	0	0	4	14
pPKP	0	0	0	0		1
S	12	38	35	0	0	1
ScP	0	0	0	0	0	1
ScS	0	1	0	0	0	0
SKS	1	0	0	0	0	0
SP	0	0	0	0	0	0
sP	4	2	1	1	1	3
sPKP2	0	0	0	0	0	0
sS	1	2	0	0	0	0
Unidentified	0	0	0	0	3	1

Table 7

STA	IPHASE	EVNAME	DELTA	MB	LAT	LON
GOL	P	198401281923284	22.76	5	17.3205	-100.12
GOL	P	1984013018 1 44	35.8	4.8	55.7564	-154.3546
GOL	P	198401282252446	35.88	4.9	9.2516	-83.8755
GOL	P	19840123 559460	38.85	4.9	20.2941	-65.9484
GOL	P	198401111135537	42.55	5	-3.0036	-103.0225
GOL	P	1984012817 4392	43.01	5	6.6627	-74.5211
GOL	P	198401 61137498	43.79	5	6.7488	-73.0643
GOL	P	19840117 417173	44.01	4.5	5.8248	-73.9573
GOL	P	1984012322 6 64	44.79	5.4	53.2611	-169.6661
GOL	P	198401171619 46	48.68	5.9	-3.9152	-81.4104
GOL	P	19840113 229 20	49.93	5.8	-3.8823	-78.4707
GOL	P	198401 52141486	50.96	5.2	51.3622	-179.2571
GOL	P	198401291614363	56.85	5.2	71.8835	-1.5914
GOL	P	198401301613510	57.36	4.4	75.4703	7.6667
GOL	P	19840117 332 80	57.73	5.1	-8.883	-71.3051
GOL	P	198401261930590	58.09	5.1	-12.2722	-76.9016
GOL	P	198401141334 64	58.62	4.8	-11.5795	-74.3015
GOL	P	19840125 717589	65.63	4.9	8.7444	-39.8998
GOL	P	19840125 659 04	66	4.9	8.6203	-39.5093
GOL	P	19840125 351451	66.05	5.1	8.6614	-39.4137
GOL	P	198401161227240	69.67	5.7	-30.0345	-112.2646
GOL	P	198401 42240417	70.96	6	45.3996	151.3144
GOL	P	198401 615 1344	71.79	5.3	-23.7739	-68.7914
GOL	P	198401 122 8121	72.1	5.4	-22.6582	-66.0139
GOL	P	19840125 935 58	77.53	5.3	42.2668	143.0713
GOL	P	198401171113418	82.58	5.6	36.5099	141.1398
GOL	P	198401241847570	84.07	4.9	-16.3865	-173.0189
GOL	P	198401 418 0 53	84.42	5	-15.6647	-174.24
GOL	P	198401 1 9 3401	87.13	6.4	33.6199	136.803
GOL	P	19840120 133248	88.03	5.2	50.6363	96.3999
GOL	P	198401221351513	88.32	5.3	-21.3032	-174.2573
GOL	P	19840120 353 34	88.94	5.3	-17.8164	-178.6029
GOL	P	198401171949582	92.61	5.4	-22.2384	-179.6396
GOL	P	198401191615155	92.66	5.8	-23.6792	-178.2983
GOL	P	19840123 734569	93.97	5.8	29.2822	130.438

35 records selected.

Table 8

**Summary of Models of the Crust Beneath the
Southern New England Crystalline Basement (SNECB)**

Depth to Top (km)	Layer Thickness (km)	Vp (km/sec)	Vs (km/sec)
SNECB (Average):			
0.0	0.2	4.39	2.54
0.2	0.2	5.00	2.89
0.4	0.6	5.19	3.00
1.0	0.6	5.81	3.36
1.6	0.8	5.54	3.20
2.4	---	5.99	3.46
SNECB (Range):			
0.0	0.2	4.22-4.74	2.44-2.74
0.2	0.2	4.79-5.40	2.77-3.12
0.4	0.6	4.98-5.61	2.88-3.24
1.0	0.6	5.59-6.28	3.23-3.63
1.6	0.8	5.31-5.99	3.07-3.46
2.4	---	5.74-6.47	3.32-3.74
Appalachians Model (Hughes and Luetgert, 1991):			
0.0	1.5	5.5-5.7	3.2-3.3
1.5	3.5	6.05-6.1	3.5-3.6
5.0	9.0	6.1-6.2	3.6
14.0	10.0	6.5-6.4*	3.8-3.7
24.0	12.0	6.7-7.0	3.8-4.0
36.0	---	8.1	4.6
Composite Model = SNECB(average) + Appalachians(midrange):			
0.0	0.2	4.4	2.5
0.2	0.2	5.0	2.9
0.4	0.6	5.2	3.0
1.0	1.4	5.7	3.3
2.4	2.6	6.0	3.5
5.0	9.0	6.2	3.6
14.0	10.0	6.5	3.8
24.0	12.0	6.9	3.9
36.0	---	8.1	4.6

* Note: This layer has a negative velocity gradient.

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Figure Captions

Figure 1: Locations of seismic stations in the former Soviet Union. (a) Stations that report (or have previously reported) seismic phase data to the ISC. (b) Stations used for demonstration of SQL queries using a database created by programs written for this project.

Figure 2: (a) Epicenters of all events reported in the ISC Bulletin for the month of January 1986 ($1.3 \leq m_b \leq 6.2$). (b) Epicenters of all events reported in the ISC Bulletin for the month of January 1984 ($1.6 \leq m_b \leq 6.4$).

Figure 3: Epicenters of all events for which at least one phase was reported by station OBN during January 1986 ($4.2 \leq m_b \leq 5.9$).

Figure 4: Epicenters of all events for which at least one phase was reported by station YAK during January 1986 ($4.4 \leq m_b \leq 6.0$).

Figure 5: Epicenters of all events for which at least one phase was reported by station BLA during January 1986 ($4.8 \leq m_b \leq 5.7$).

Figure 6: Epicenters of all events for which at least one phase was reported by station GOL during January 1986 ($4.1 \leq m_b \leq 5.9$).

Figure 7: (a) Geometry of the original Weston Seismic Array (WESSA) in eastern Massachusetts. (b) Geometry of the expanded array. In both maps all locations are shown relative to the reference site (Site A).

Figure 8: (a) Examples of seismograms recorded by the WESSA from a quarry blast detonated at the San-Vel quarry in Littleton, MA (a distance of 25.0 km from the array). The waveforms have been corrected to a standard instrument response. (b) Spectral amplitude ratios for channels 1, 7 and 8 relative to channel 3.

Figure 9: Map of tectonic regions in southern New England (SNE). Shaded area indicates a broad region in SNE where R_g dispersion generally suggests a laterally homogeneous seismic velocity structure in the shallow crust.

Figure 10: Mean and standard deviation of Rg group velocities for paths contained within the SNECB (closed circles) and within the central part of the Hartford Rift basin (open triangles).

Figure 11: Three dimensional plot and contour map of group velocity for Rg waves with a period of 0.7 sec in the area surrounding the San-Vel quarry in Littleton, MA. On the contour map, the quarry is indicated by a star, the stations are indicated by dots, and the trace of the Clinton-Nebury fault zone is shown by the dark solid line.

Figure 12: Examples of shear wave velocity models determined in our study of the lateral variation of the shallow crust beneath southern New England (described in Scientific Report No. 3). The model labelled "Block 13" was obtained from tomographic inversion of Rg group travel times and corresponds to the resulting dispersion curve for one of the blocks in that inversion. Block 13 surrounds one of the deeper parts of the Hartford Rift basin, and the velocity model shown by the open squares represents our model of the shallow crust underlying that block. The open circles labelled SNECB represent our average model of the shallow crust underlying the southern New England crystalline basement.

Figure 13: Range of shear wave velocity models for various parts of the southern New England crystalline basement (SNECB) obtained from tomographic inversion of Rg group travel times and resulting dispersion curves.

Figure 14: Composite model of the crust beneath the SNECB. This model was created by combining the results of our inverted Rg model for the average structure underlying the SNECB with the refraction/wide-angle reflection model of the Appalachians described by Hughes and Luetgert (1991). The models were "connected" together at depth of about 3 km.

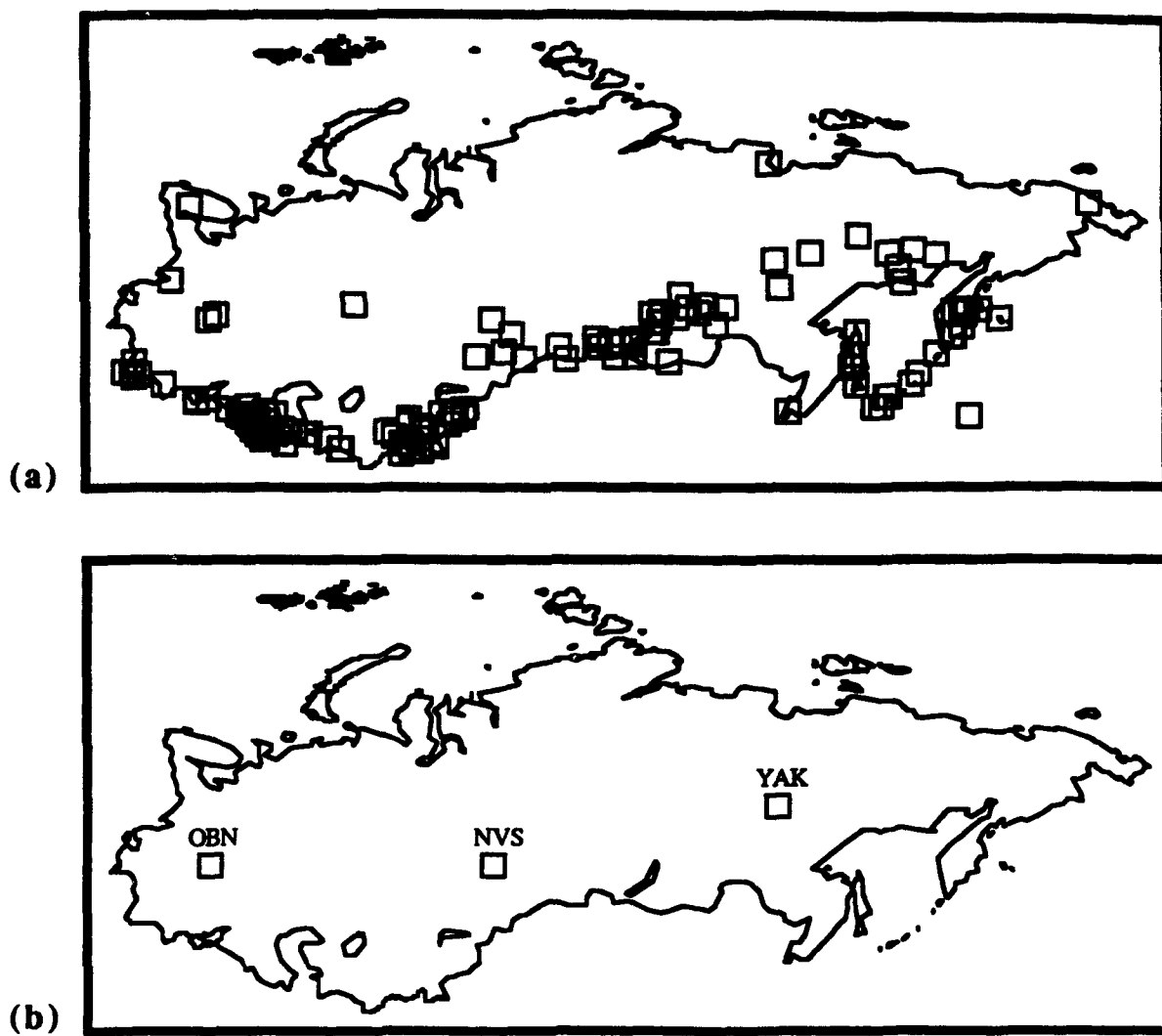
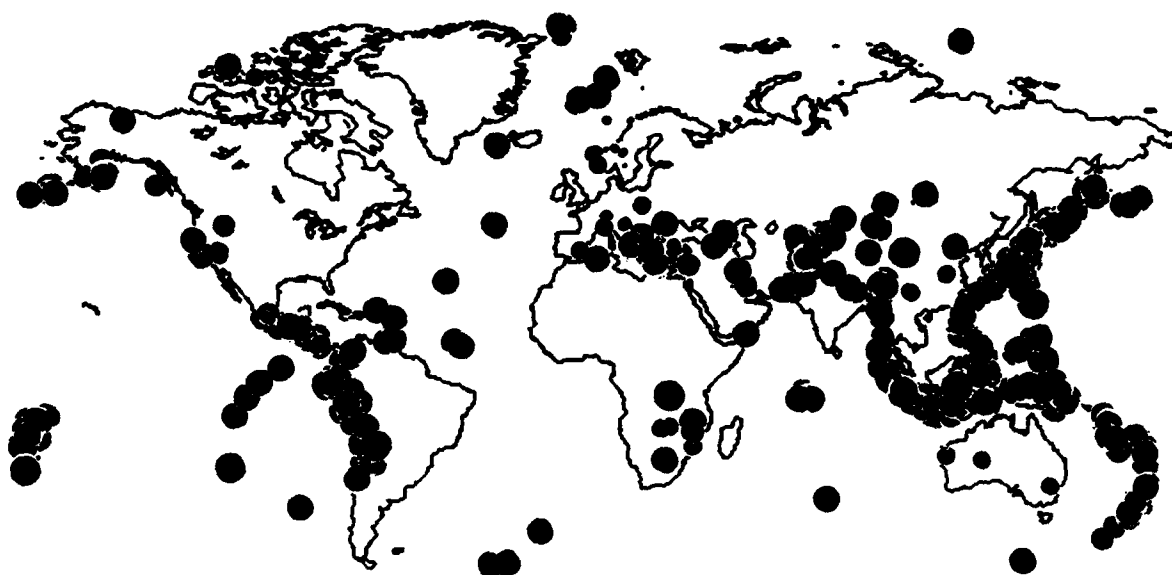


Figure 1



(a) January 1986 ($1.3 \leq m_b \leq 6.2$)



(b) January 1984 ($1.6 \leq m_b \leq 6.4$)

Figure 2



Figure 3



Figure 4



Figure 5



Figure 6

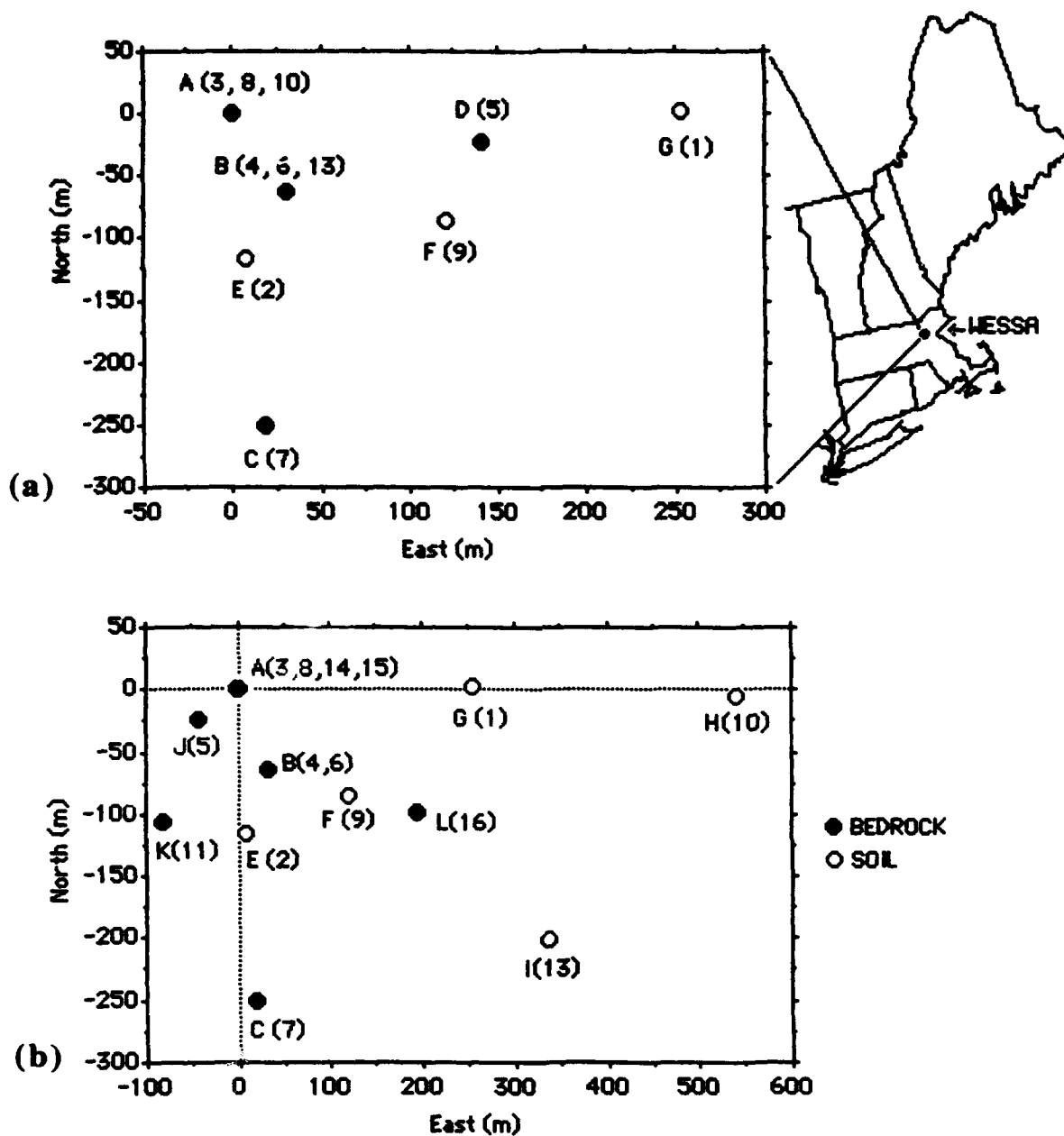


Figure 7

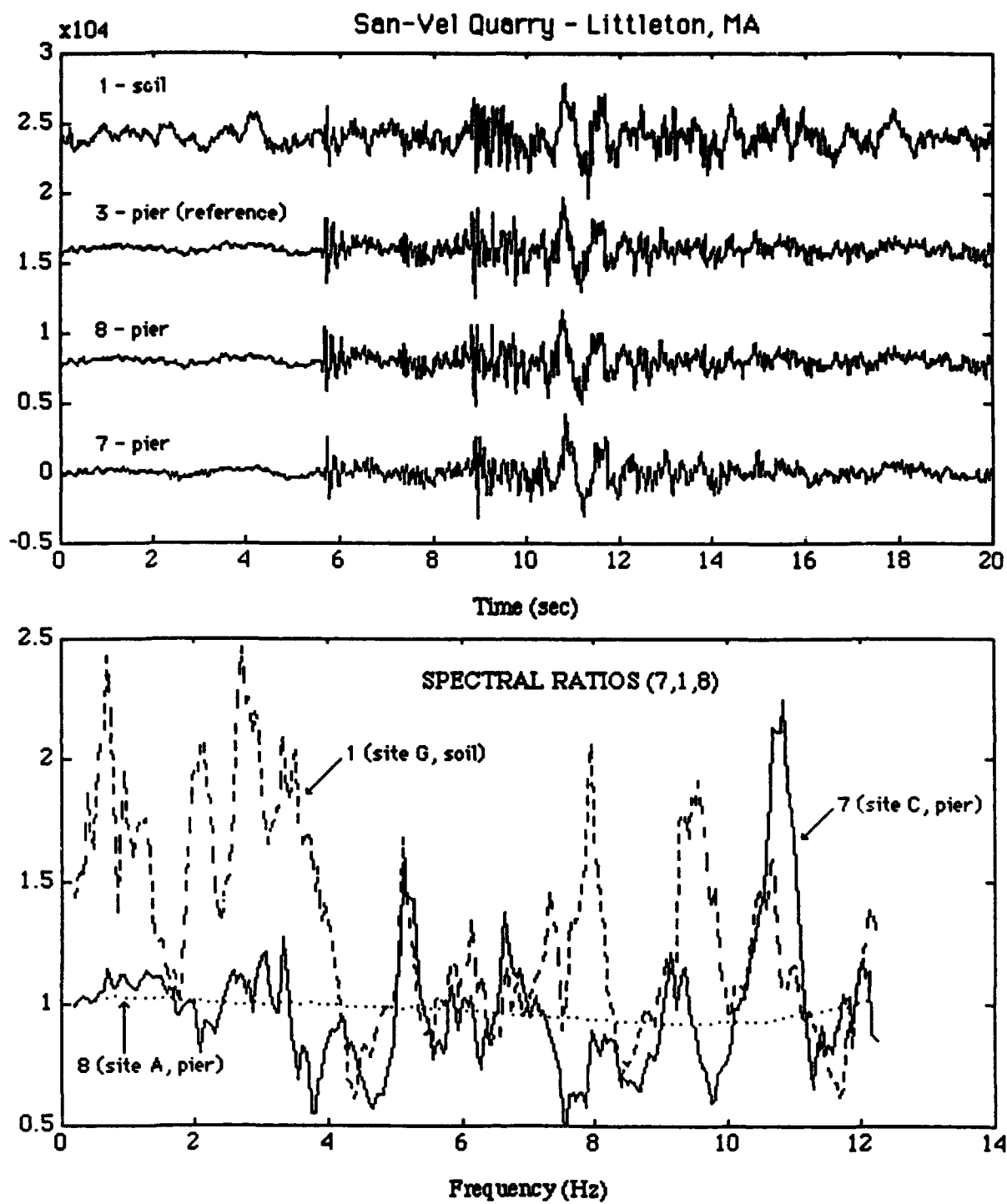
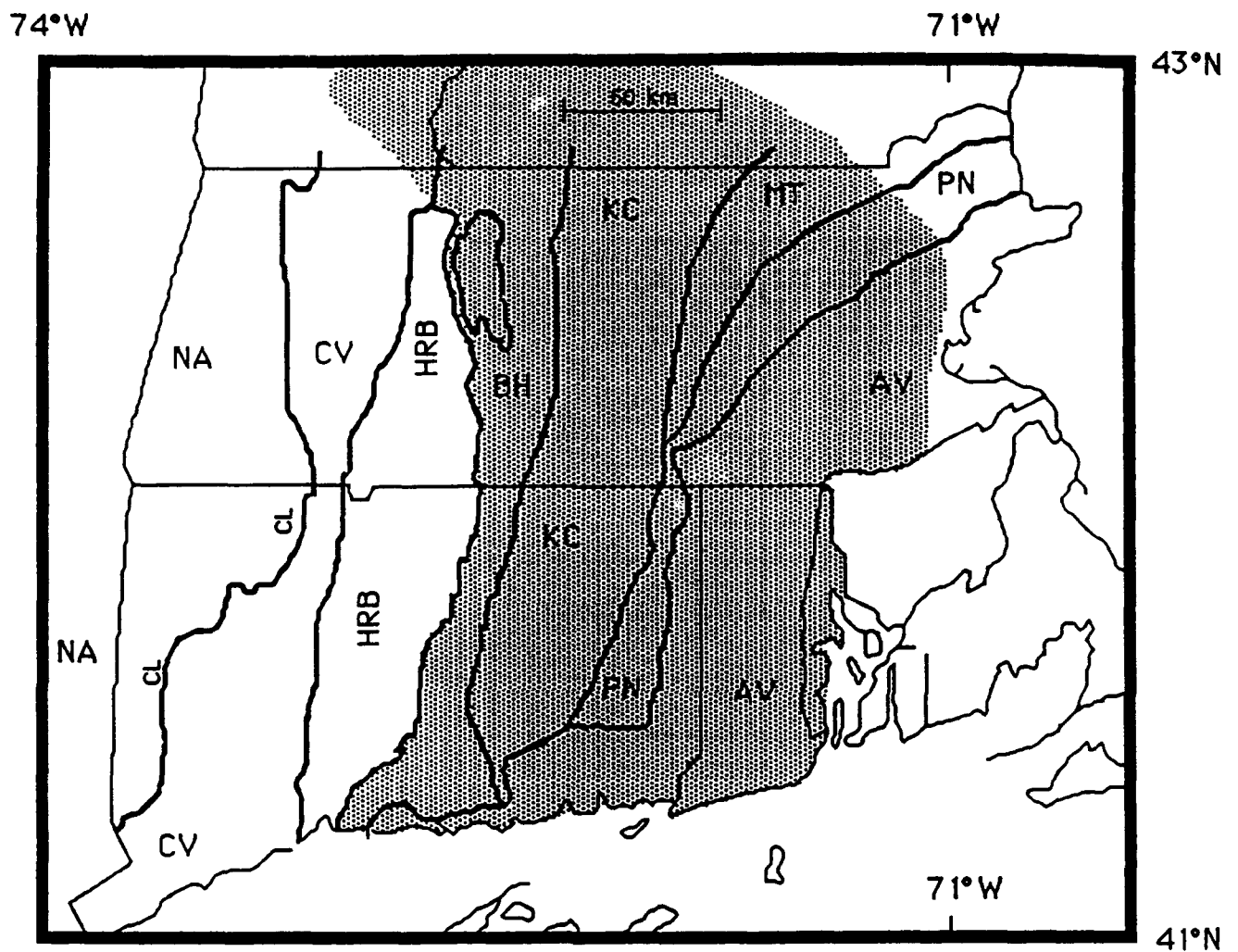


Figure 8



NA = Proto-North American Terrane
 CV = Connecticut Valley Synclinorium
 CL = Cameron's Line
 HRB = Hartford Rift Basin
 BH = Bronson Hill Anticlinorium

KC = Kearsarge-Central ME
 Synclinorium
 MT = Merrimack Trough
 PN = Putnam-Nashoba Terrane
 AV = Avalonian Superterrane

Figure 9

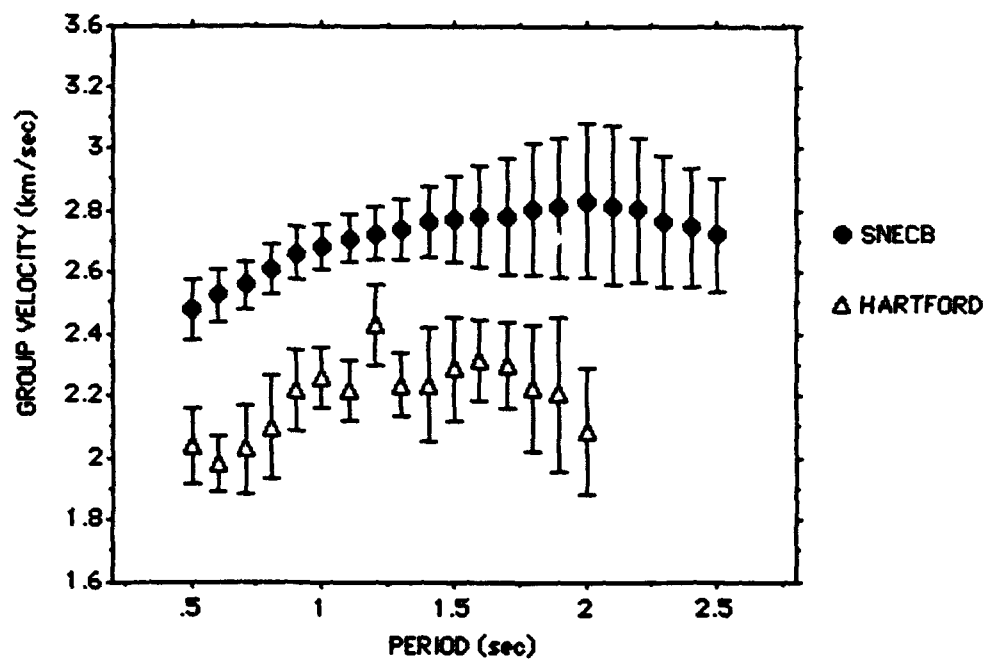


Figure 10

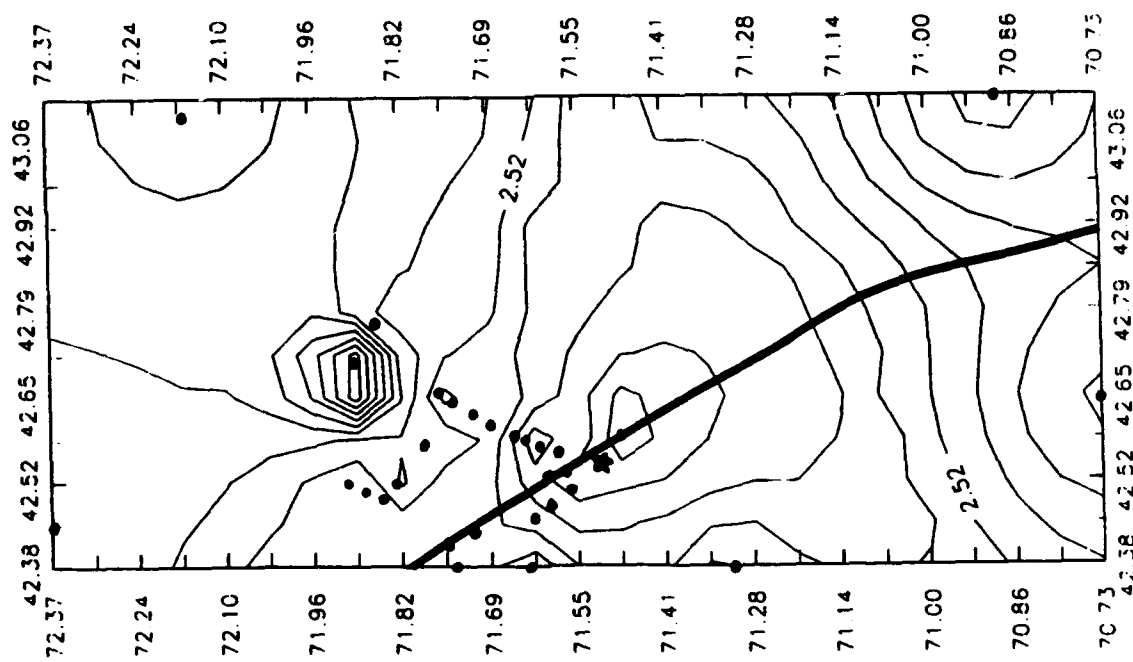
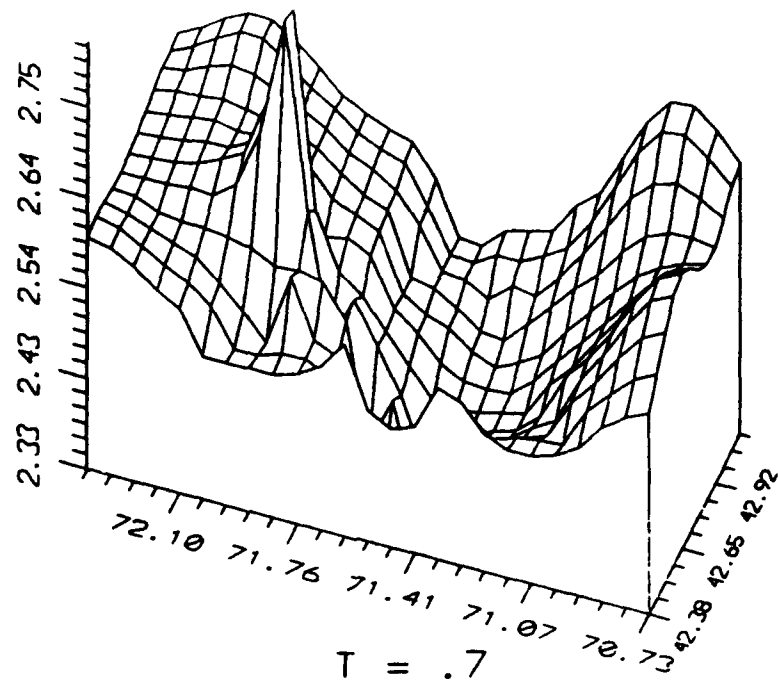


Figure 11



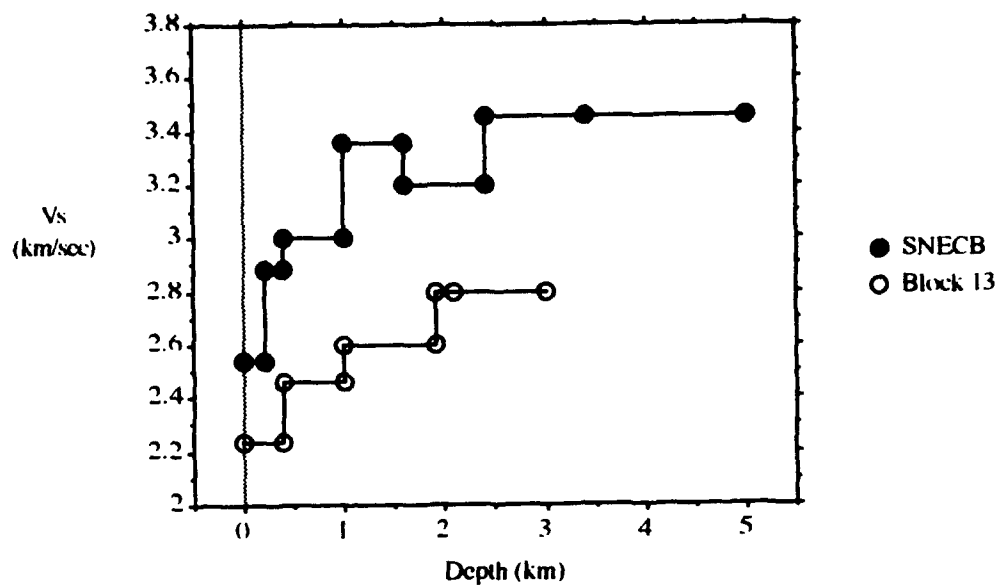


Figure 12

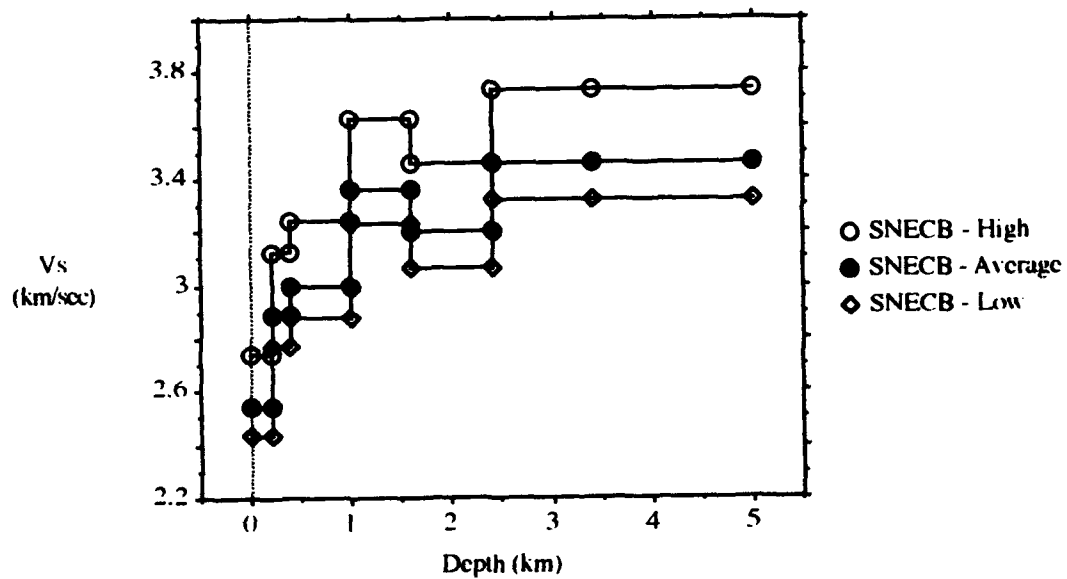


Figure 13

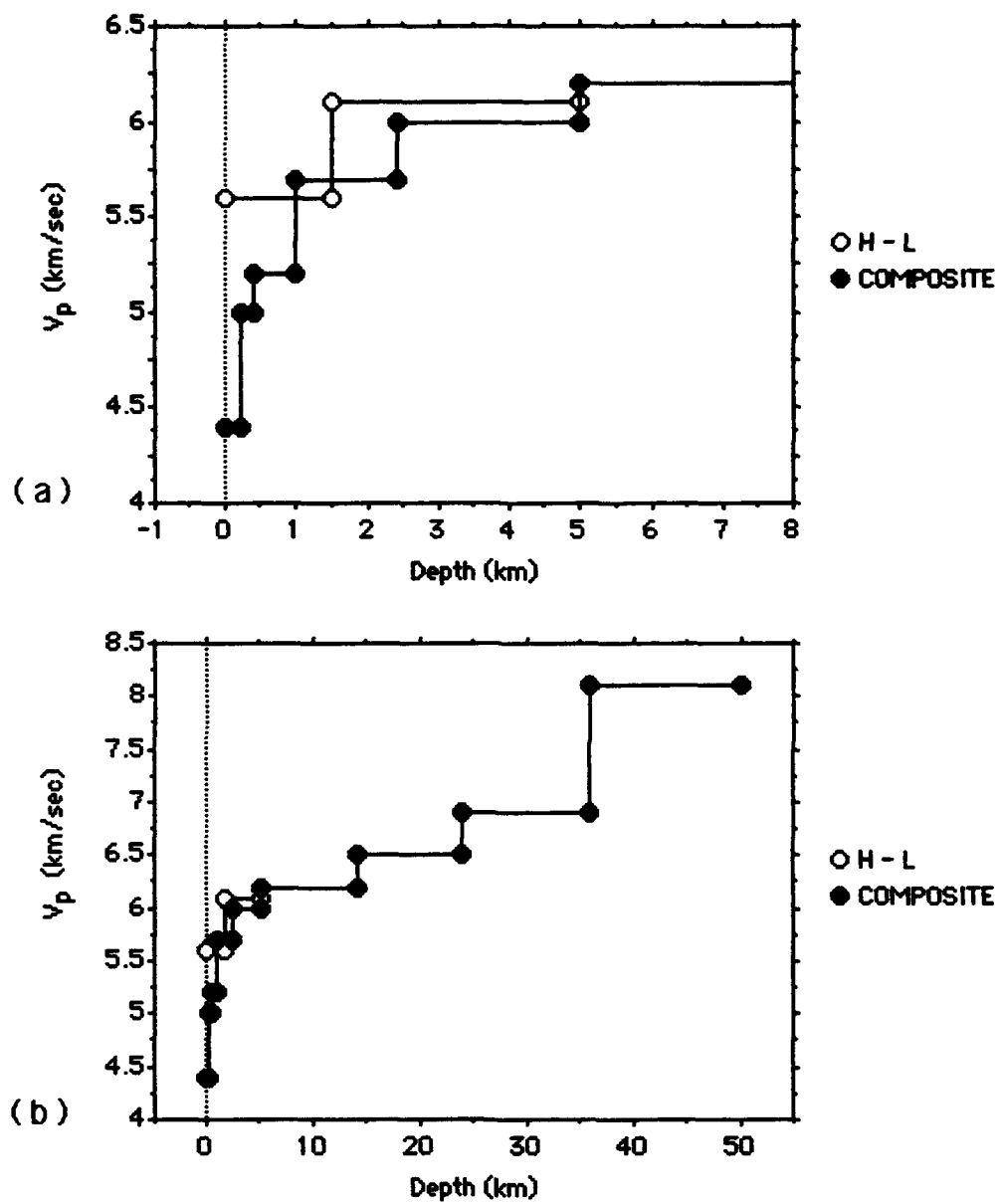


Figure 14

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